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ENERGY SCIENCES NETWORK

ESnet6 High Touch Services

Precision Streaming Network Telemetry

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Office of Science

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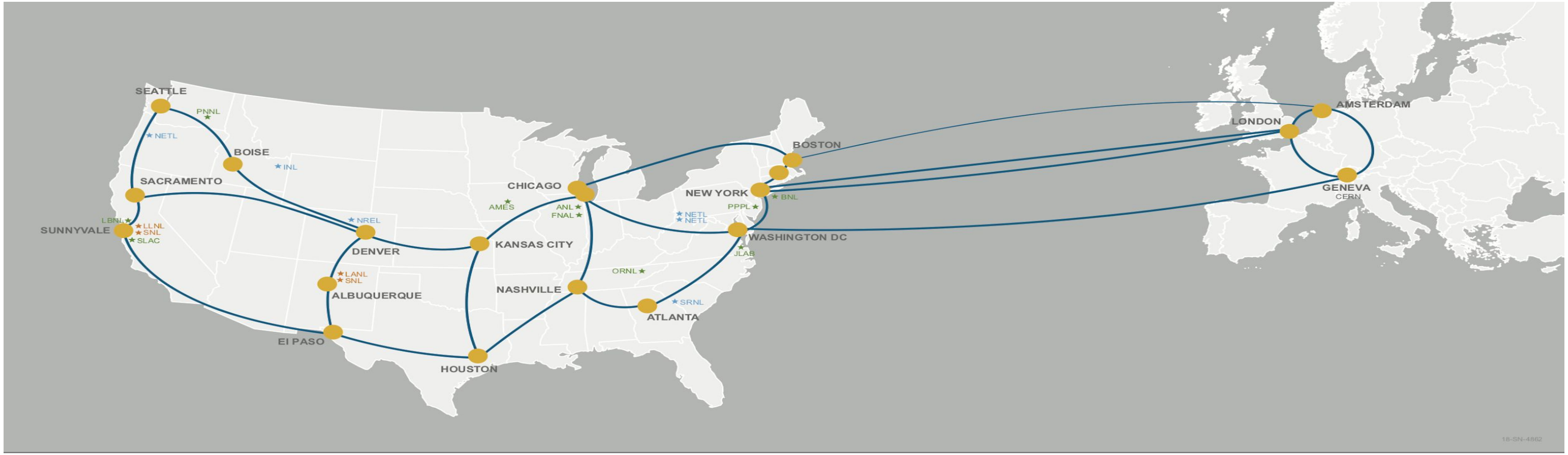
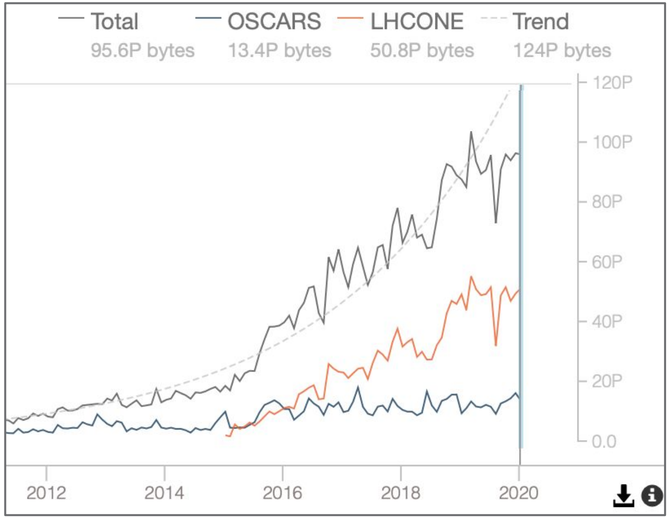
ESnet: DOE’s high-performance network (HPN) user facility optimized for enabling big-data science



ESnet provides connectivity to
all of the DOE labs, experiment sites, & supercomputers

Increased Need for Programmability

- ESnet's traffic, user-base and the experiments continue to grow in a fast pace
- Computing and data model are also evolving, requiring:
  - fine-grained visibility in real-time
  - application-specific traffic handling
  - programmable, in-network services
- Needs not addressed by existing measurement mechanisms (sampled, aggregated, delayed)
- High Touch Services created to fulfill these needs



Live ESnet usage statistics: my.es.net
Total carried: Exabyte/year.

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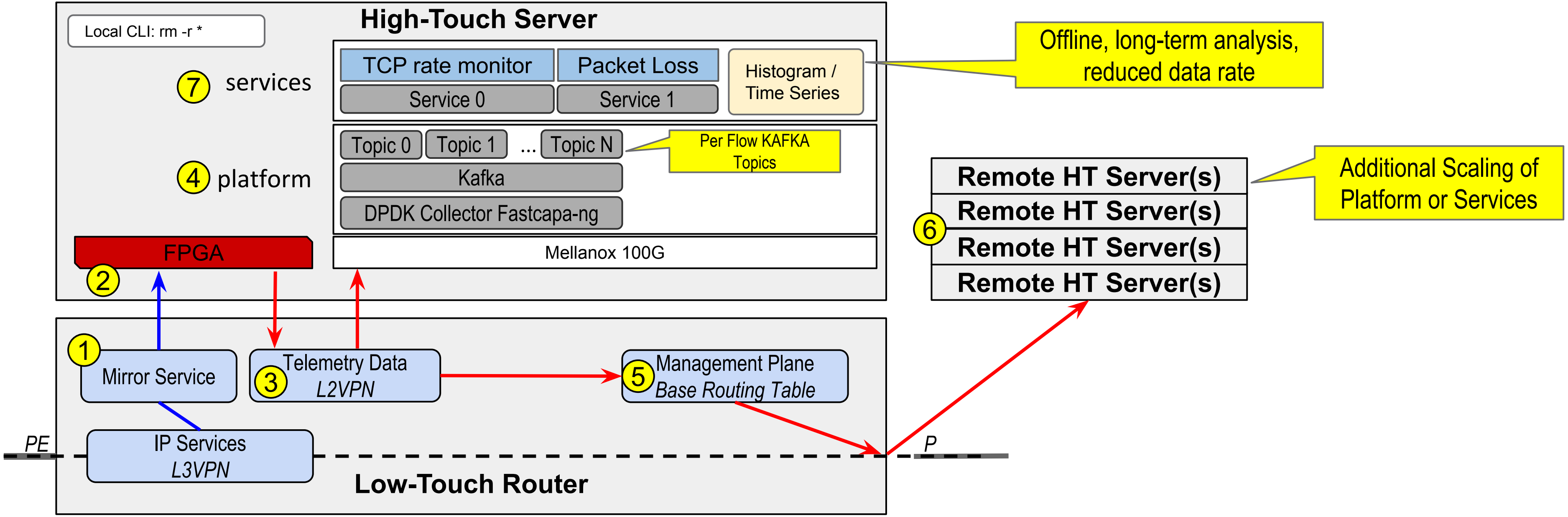
High-Touch Services

- High-precision, real-time visibility into network traffic
  - Process every packet of interest in real-time
  - Accurate, precision timing (ns precision / accuracy)
  - Software-defined functionality
  - Programmatically deployable and customizable
- In contrast to "low touch" services
  - Fixed function services such as IP packet routing, basic statistics
  - Optimized for speed and low cost, but not flexible
- Technology enablers
  - Software-defined networking
  - Programmable network dataplane hardware with accurate timestamps
  - High-speed packet processing libraries (DPDK, etc.)

ESnet6 High-Touch Architecture Overview



1. Mirror Service - Allows selective flows in the dataplane to be duplicated and sent to the FPGA for processing.
2. Programmable Dataplane (DP) - Appends meta-data, timestamps and repackages packet for transmission to Platform code.
3. Telemetry Data L2VPN - Connect Dataplane and Platform, possibly on different High-Touch Servers.
4. Platform - Reads telemetry packets from the network and distributes information to High Touch Services.
5. Management Plane Base Routing Table - Provides connectivity to Remote Servers.
6. Remote Server - Hosts Platform components or Services (but not a Dataplane). Telemetry data can be directed to Remote Servers.
7. Service - Reads data from the Platform and performs real-time analysis as well as inserts selected telemetry data into database.

Datapath of Customer Packet
Datapath of Mirrored Packet
Datapath of Telemetry Packet

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What Programmable "High Touch" Hardware to Use?

- There are a variety of programmable network devices available today. ESnet was looking for the following:
  - 100Gbit/s port speed and roadmap for higher speeds
  - Timing and performance guarantees
  - Easy programming (P4 style)
  - Established vendor with support
- We are currently prototyping using Xilinx FPGAs
  - Alveo U280: 2x100G port, 8GB HBM2 memory (3.2 Tbps bandwidth), 32GB DDR4, 1.2M logic cells

Xilinx Kintex UltraScale (FPGA)+

Xilinx U280 FPGA card

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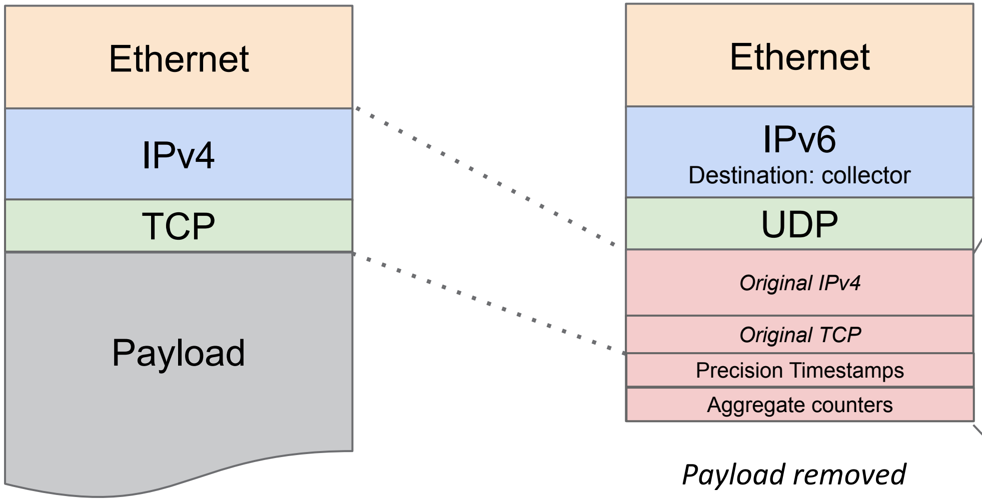
Telemetry Producers



Payload removed

Copy of original packet of a TCP flow

Programmable Data Plane
Transforms packets

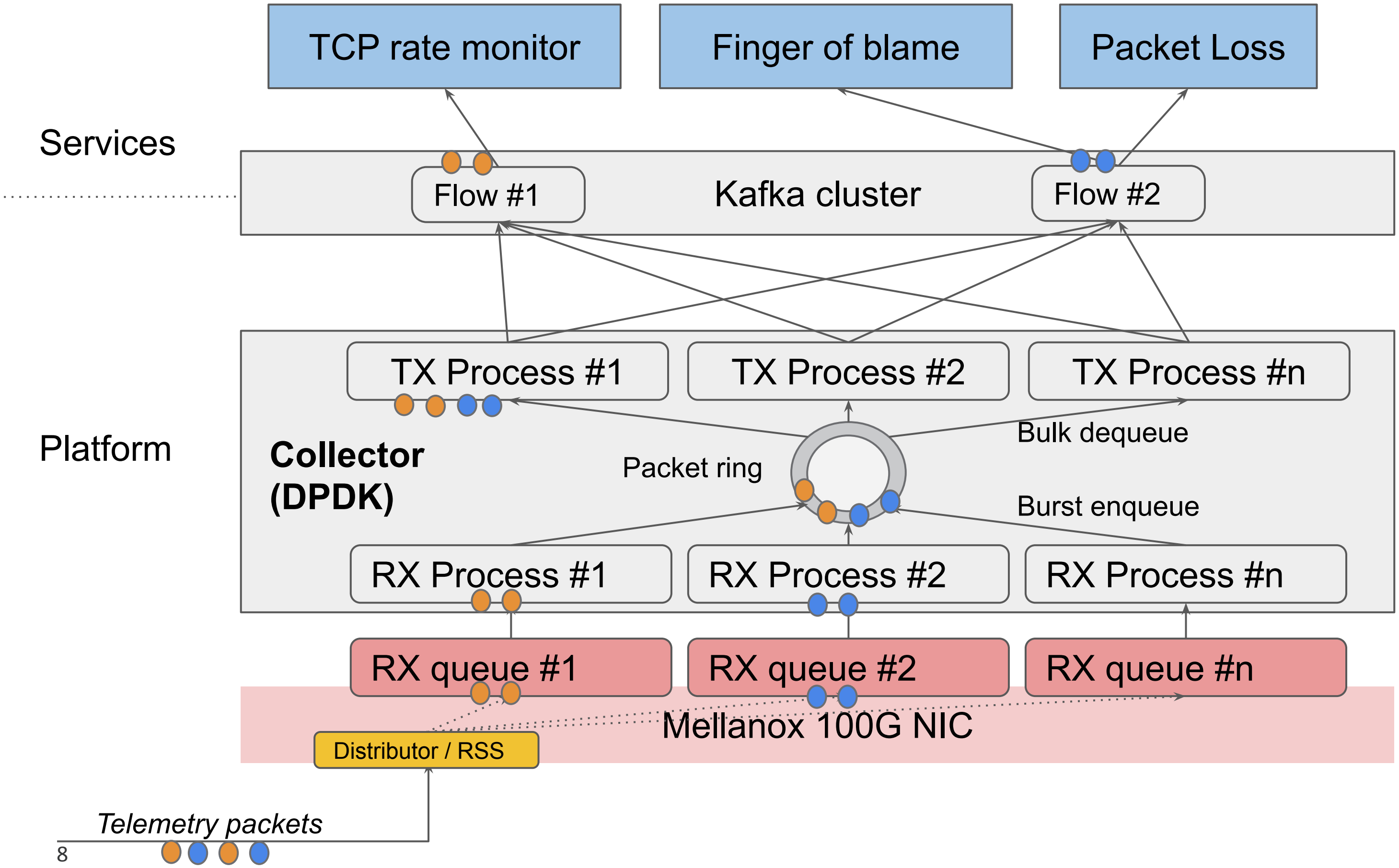
High-Touch Telemetry Packet

Packet size	Rate	Telemetry PPS	Telemetry Rate
1500B	10Gb/s	812K	1,079Mb/s
1500B	100Gb/s	8,127K	10,790Mb/s
9000B	10Gb/s	138K	183Mb/s
9000B	100Gb/s	1,383K	1,833Mb/s

```
type HighTouchLayer struct {
        Version           string
        SensorID          uint8
        VlanId             uint16
        IngressTimestamp  uint64

        // IP header of original packet
        IpSrcAddr        net.IP
        IpDstAddr        net.IP

        // TCP header of original packet

        TcpSrcPort   uint16
        TcpDstPort   uint16
        TcpSeqNo     uint32
        TcpAckNo     uint32

        // Aggregate counters
        FlowPktCount  uint64
        FlowByteCount uint64
        FlowId         uint16
        Flags          uint8
}
```

High-Touch Telemetry Record (approximate) ~100 bytes

High Touch Collector Processing



Topics deleted after 24hr automatically

Fastcapa runs on multiple cores (each RX and TX process is one core)

Any DPDK-enabled card

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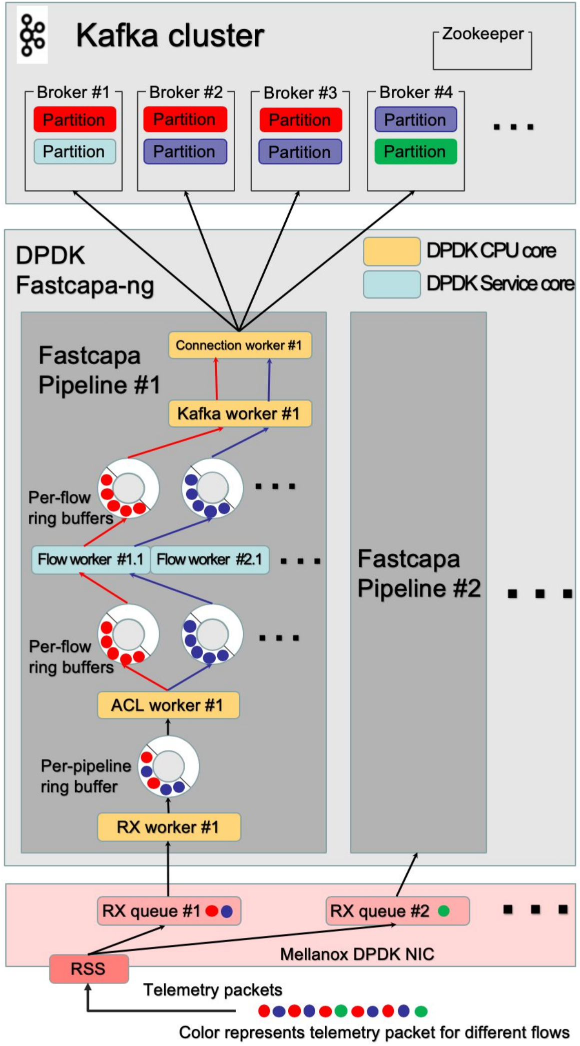
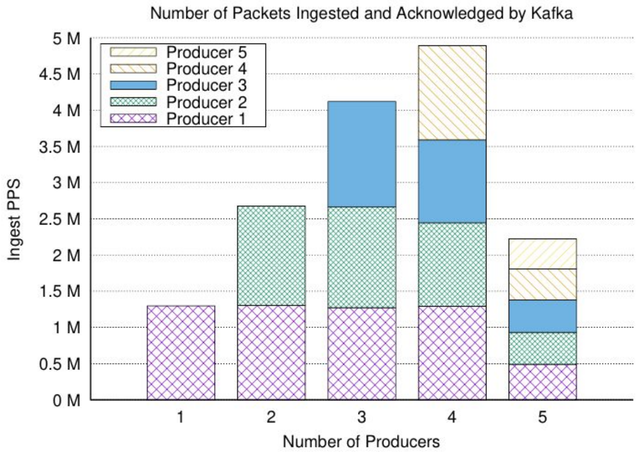
ESnet Fastcapa-ng Internals

- RX queue:
  - NIC dma packets into memory
  - RSS (Receive Side Scaling) applied
- RX worker:
  - pull packet into ring buffers
- ACL worker:
  - classify flows and send them to dedicated rings.
- Flow worker (service cores):
  - process flows using different function: passthrough, sampling, histogram, etc.
  - Flexible N to M mapping of flow to service cores.
- Kafka worker:
  - Combine multiple telemetry packets into large kafka messages.
- Dedicated Kafka connection:
  - maintain TCP connection, message compression task.



Kafka setup and benchmarking

- Docker-compose: bitnami/kafka, JMX Exporter, Prometheus, Grafana
- 6 brokers on a single server
- Possible bottlenecks:
  - Librdkafka C client (inside Fastcapa-ng)
  - Docker proxy - network
  - CPU - Fastcapa and Kafka brokers are on the same host



~5M PPS ingest
untuned single server / 6 broker

Use Case #1
TCP Rate and Retransmission Tracking

Motivation:

- Monitoring TCP rate in a per-packet basis
    - Find peaks, abnormal rate in the shortest possible time
- Provide a tool for network operations and engineering
- Finding packet retransmissions as they happen
    - Is there an issue at ESnet or at the source or destination networks?

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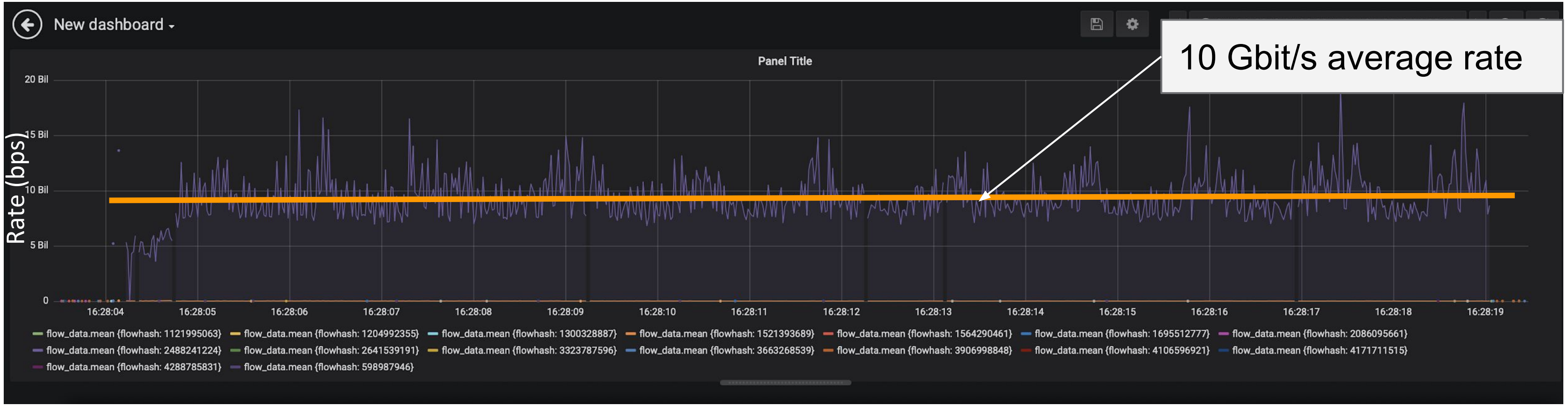
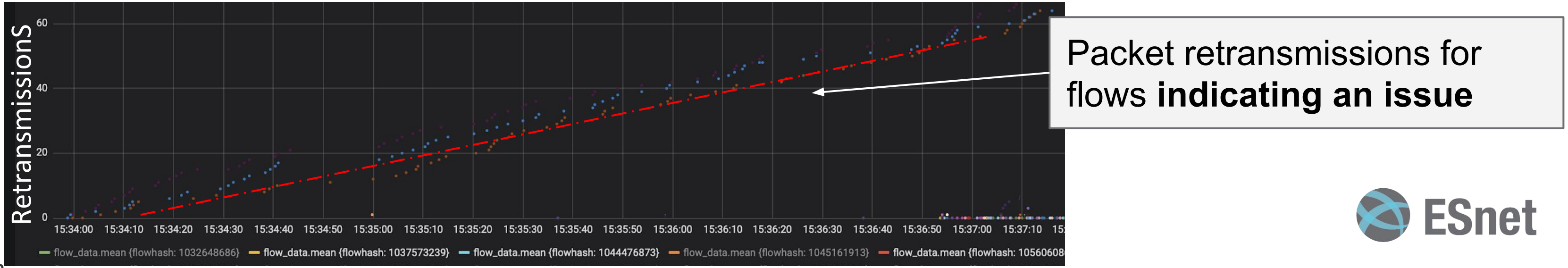
Visualizing Real-Time Telemetry Data

- We can plot metrics for every packet in a flow using InfluxDB / Grafana



A sample PerfSonar 10Gbit/s test measured by High Touch Rate Monitor



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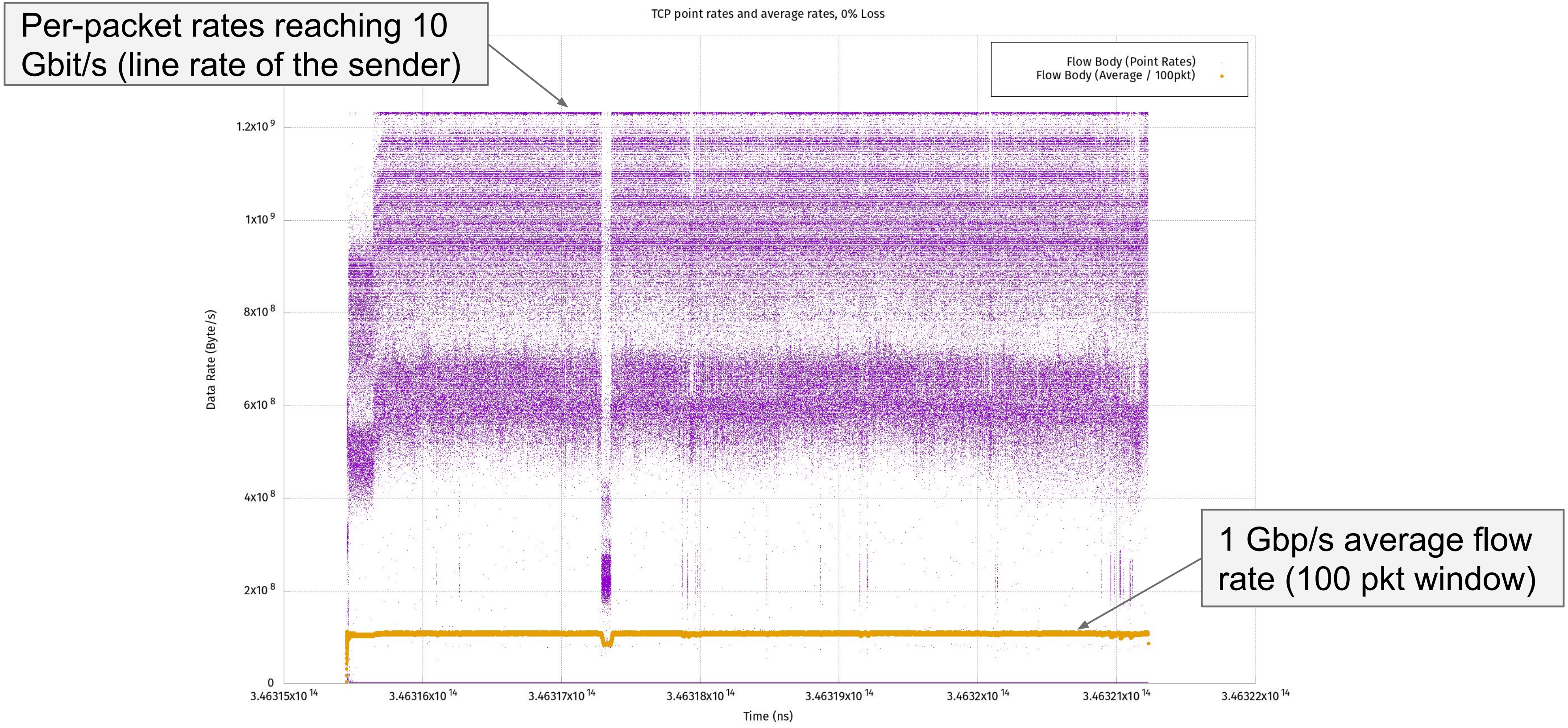
1 Gbps iPerf Flow - 600,000 Packets



Note: Average rate is calculated using a time-weighted average of per-packet rates.

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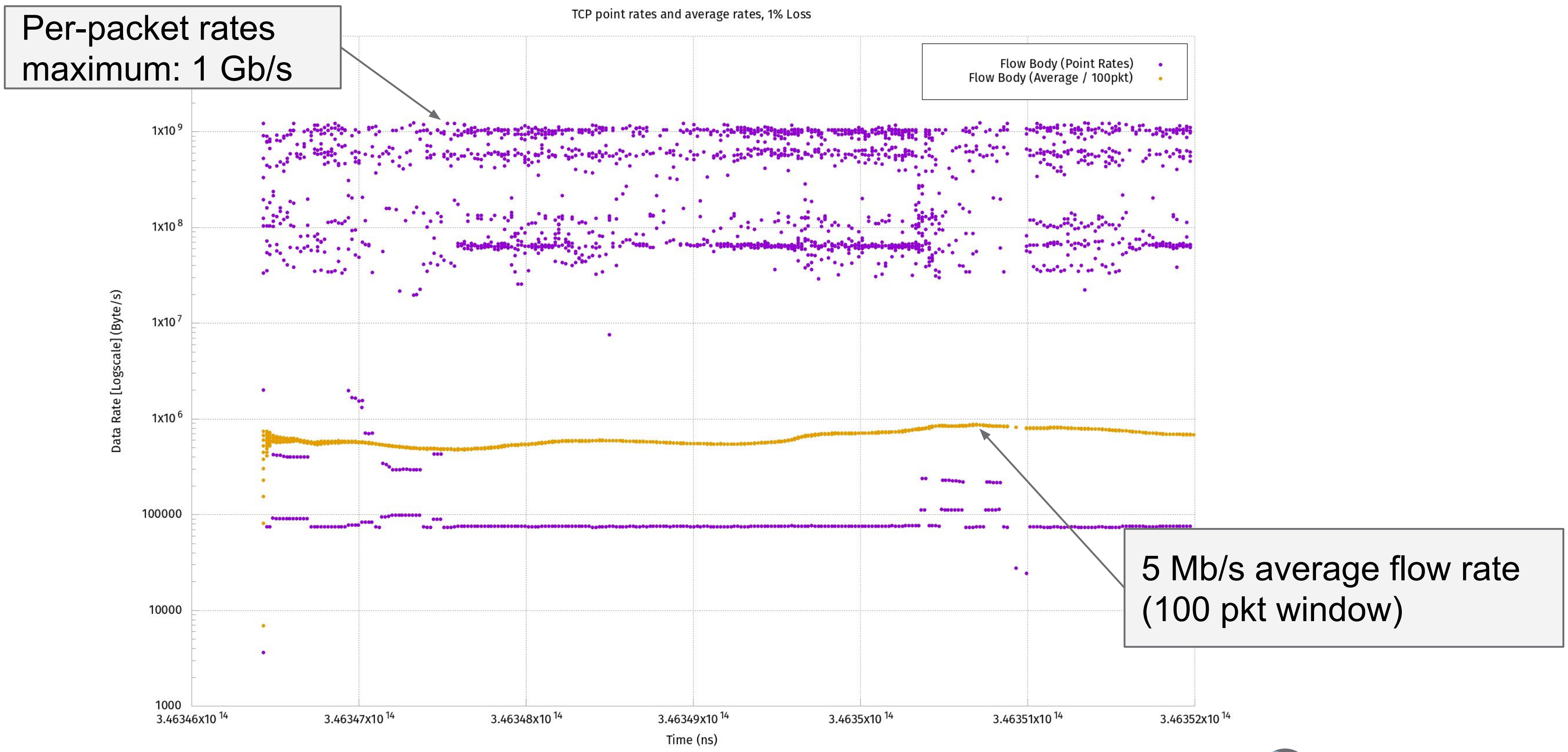
1 Gbps iPerf flow - 1% packet drop



Note: only 23 packets were dropped all together, taking bandwidth down to 5 Mb/s from 1 Gb/s.

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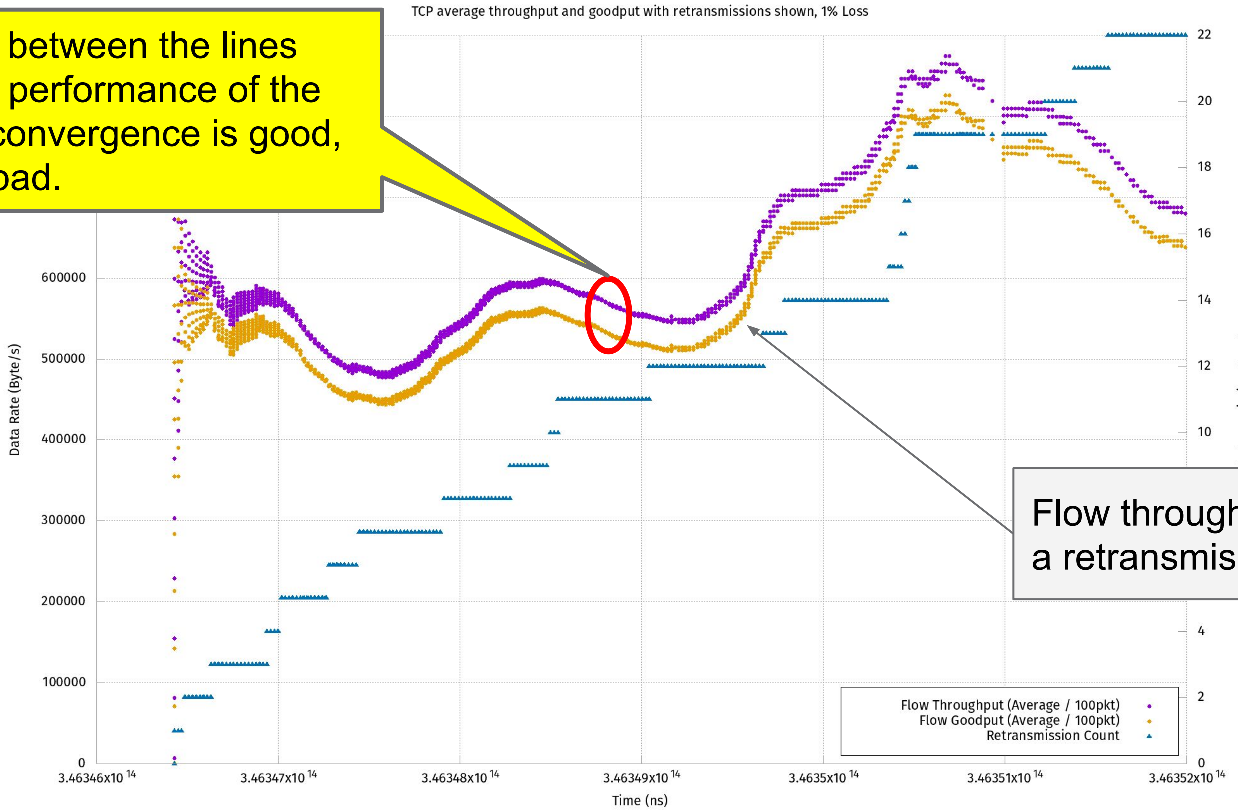
1 Gbps iPerf Flow - 1% Packet Drop

The difference between the lines represents the performance of the data transfer, convergence is good, divergence is bad.



Flow throughput drops when a retransmission happens

Use Case #2
TCP Congestion Control Identification

- Motivation:
  - Some flows are unable to utilize the available bandwidth
  - TCP flows can take more of their fair-share
- Discovering misconfigured flows (e.g., window parameters, congestion control) will allow us:
  - Tune the configuration of Data Transfer Nodes
  - Notifying our sites automatically (periodic reports) on suboptimal configuration
  - Guide fair usage of the network ("is equal bandwidth share" fair?)

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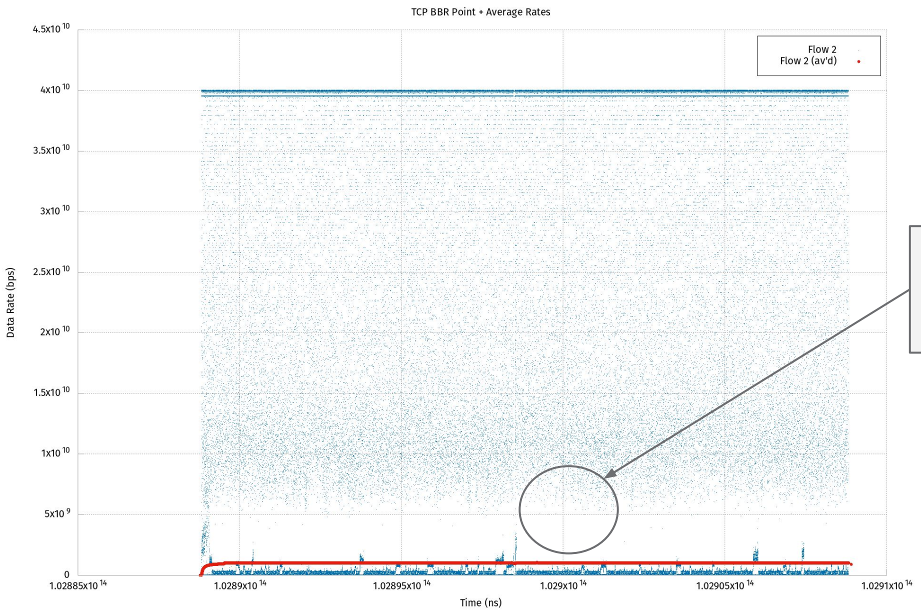
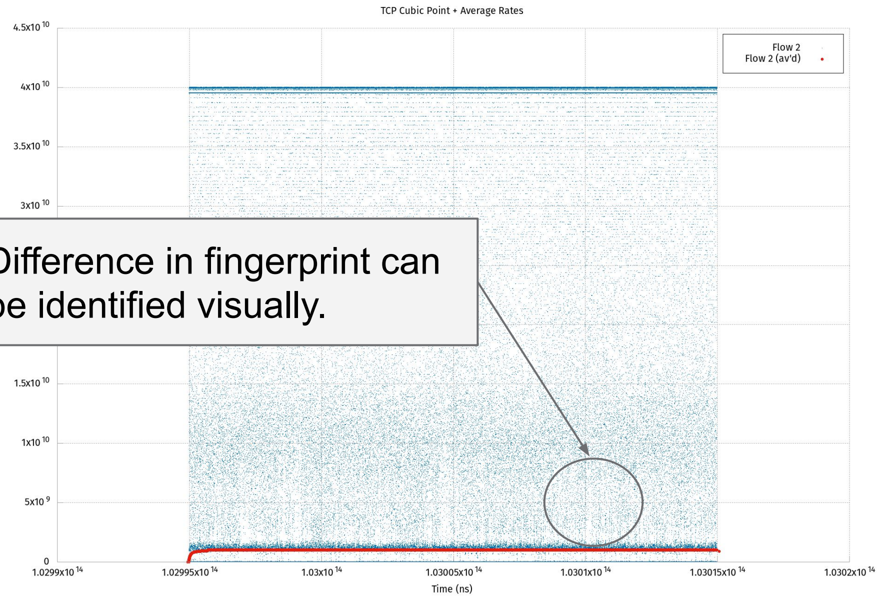
BBR vs Cubic - Point Rates



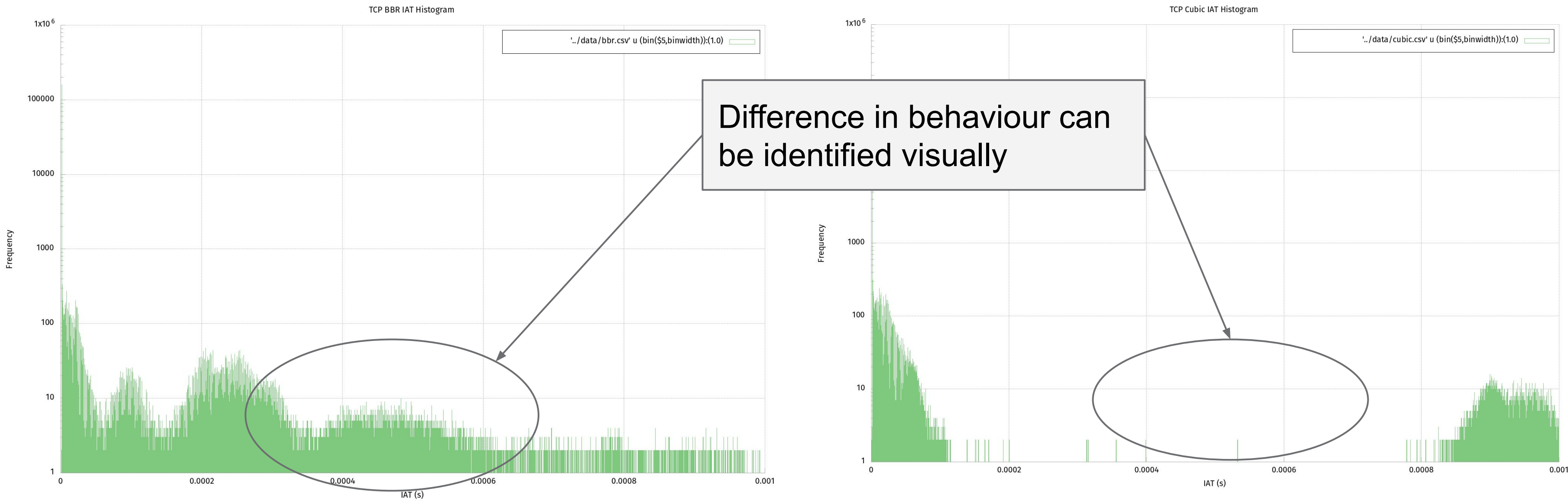
TCP BBR



TCP Cubic

2 millions of data points shown (around 600.000 points a second generated)

BBR vs Cubic - Inter-Arrival Time Histogram



TCP BBR (delay-based)

TCP Cubic (loss-based)

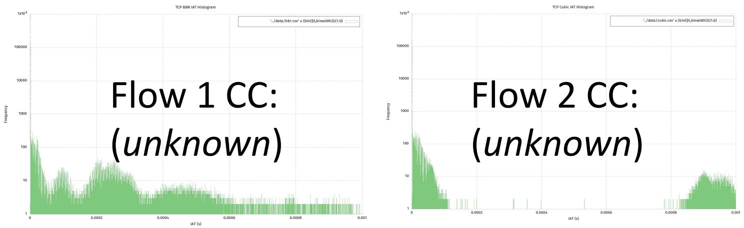
BBR: inter-packet timing is more widespread than other congestion control algorithms.

Machine Learning on Aggregated Data

- Aggregated data - such as histograms can be used to tell apart congestion control (CC) used by TCP flows
- We are using data plane histograms of inter-arrival times per flow (2000 packets per histogram)
- ML algorithms explored: Convolutional Neural Networks, k-Nearest Neighbors

More details, dataplane architecture, ML code in:

Simpson, Kyle A., Richard Cziva, and Dimitrios P. Pezaros. "Seiðr: Dataplane Assisted Flow Classification Using ML." IEEE GLOBECOM, Taipei, Taiwan (2020).



Input: per-flow histograms of Inter-Arrival Time (IAT)

Machine Learning
(trained with labeled data)

Inference in less than 1 ms in all cases

Flow 1 CC: most likely *TCP BBR*

Flow 2 CC: most likely *TCP RENO*

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High Touch Application Programming

- High Touch Applications can be implemented using **Kafka Streams** - an easy way to program real-time applications on stream of data.
- Expressive, highly scalable and fault tolerant API that allows: aggregation, filtering, counting, grouping data...

APACHE kafka
A distributed streaming platform

```
int THRES = 10;
KTable<Windowed<String>, Long> SYNcounts = stream
      .filter((k, telemetry) -> telemetry.isSYN())
      .groupBy((k, telemetry) -> telemetry.getIPDstAddr())
      .windowedBy(TimeWindows.of(Duration.ofSeconds(5)))
      .count(Materialized.with(String(), Long()))
      .filter((key, value) -> value > THRES);
SYNcounts.toStream().to("syn-attacks");
```

Example: High Touch SYN Flood Detection

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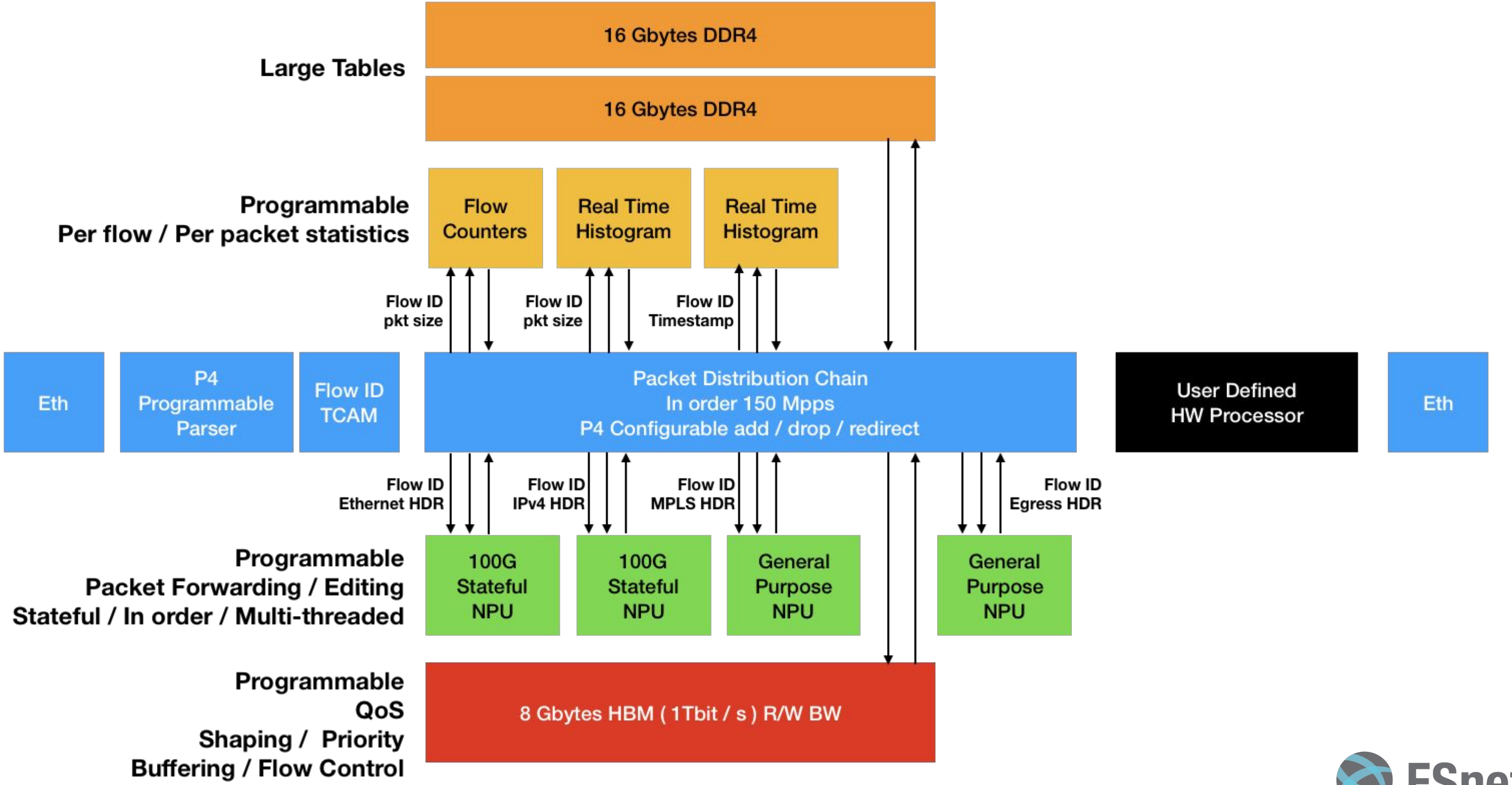
High Touch Services
DEMO

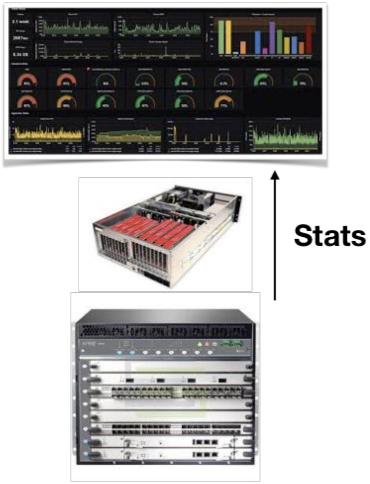
ESnet FPGA Block Diagram - Present and Future



3 models for using FPGAs

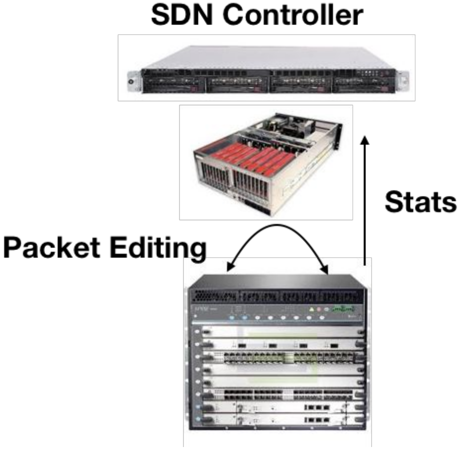
Easy

Install a copy of ESnet's telemetry solution. Zero FPGA development. Customize Splunk / Kentik / Grafana / ELK etc..



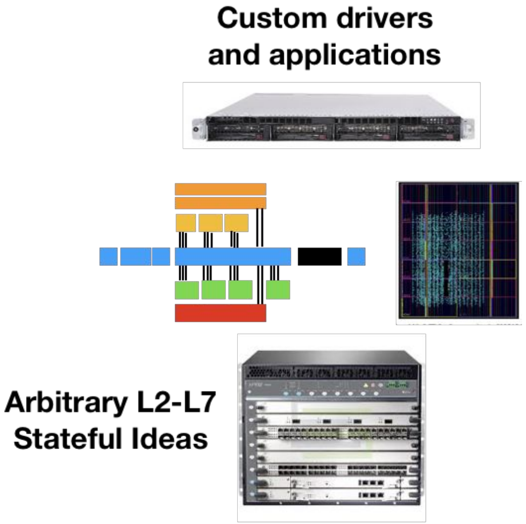
Intermediate

Program the embedded NPUs. Zero FPGA development. FPGA bit file provided. But packet editing is programmable like an SDN switch.



Advanced

Re-configure the FPGA using P4 and Verilog. User defined hardware.



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High Touch Services Timeline

2019 Q3 — Service Design

Technical service design, experimentation with dataplanes and collector software.

2020 Q1 — Design Validation

Evaluation of the collector software, dataplanes, scoping and prototyping.

2020 Q4 — Design Refinement

Making the service more robust, implementing a variety of High Touch services, while enhancing scalability, fault tolerance, security, orchestration.

2021 Q1 — Pre-Pilot

Deploying pilot service, inspecting traffic on selected links (low-traffic customer, high-traffic customer, Splunk integration).

2022 Q1 — Pre-Deployment

Finalizing a complete solution: edge hosts, programmable hardware, services and their orchestration.

2022 Q3 — Deployment

Deploying High Touch services.

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Questions…

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